Is flood risk in the Sacramento-San Joaquin River Delta increasing?

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The Delta is influenced by both rivers and coastal processes

Will sea-level rise and more intense mega-storms increase water levels and flood risk?
Approach:

1. Analyze 100+ Water level gauges from 1982-present in the Delta to determine factors that influence water level
   --Nonlinear regression

2. Recover and evaluate historical records back to the 1800s
Strategy: Rescue, digitize, and analyze ‘lost and forgotten’ records

State publication of gauge data, 1965
Years of Found/rescued data: >1800 years
Total digitized (4/10/2023): 1149 years
Factors that influence daily mean water levels

- 1 meter of storm surge in San Francisco = 0.5-0.9 meter of increased water level (WL) in Delta
- Westerly winds increases WL by up to 20 cm (average ~ 5cm)
A large flood raises water levels much more in eastern Delta than in western Delta and Bay.

Exports to water project a minor influence in southwestern delta.

Not shown: Spring-Neap tide variations of up to 20 cm in daily mean. (Water stored in delta during periods of large tides)
Factors that influence daily mean water levels

Tidal Range varies hugely!
Factors that influence daily mean water levels

- Sea Level Rise is highly variable in Delta
  - ~ -1 to 11 mm/yr
  - Rio Vista: 7.2 mm/yr
  - Antioch: 1.6 mm/yr
  - San Francisco: 3.5 mm/yr

(Global rate: ~3.5 mm/yr)

Reason for variation: Subsidence! Many parts of Delta are sinking.
How forcing is changing: River Flow

Moftakhari et al., 2013, 2015 (Based on SF tide gauge and Sacramento river gauge)

Net Delta Outflow

- Average flow has shifted to winter from spring-melt
- No evidence (yet) for increasing winter floods
- 25-30% decrease in total volume to ocean
- 1862 flood the largest on record
Since the late 1800s...

- Tidal Range appears to have decreased in the western delta
- Tidal Range has increased in the eastern delta
- Increase of ~7%/century in SF (Jay 2009)

Reasons: End of hydraulic mining sediment pulse, channel deepening, wetland reclamation
Is there evidence of change to flood risk?

**Black:** 1976 Army Corps analysis of risk, based on 1930-1970s data

**Red:** Preliminary Analysis of 100 y flood level, using modern data

Take Home: No Evidence yet for changed flood risk. More work needed to quality assure and evaluate historical records

**But...**
Some high waters are now very close to levee crests

- Sacramento River
  - Subsidence in many levees, but...
  - Lots of freeboard in many places because....
  - Upstream reservoirs reduced high water relative to pre-1940 situation

- San Joaquin River
  - Regions of subsidence exist, but
  - High water close to levee crest
  - Flooding more likely

Blue: subsidence between 2007 and 2017 Lidar survey
Also....

The future ain't what it used to be.

(Yogi Berra)
Predictions of future Cumulative Precipitation

Huang & Swain, 2022

- Future cumulative precipitation over a 30d period may be 35-60% larger in Northern/Central California in a climate future (2170s) than 1996-2005 decade
  - Based on “Arkstorm” scenario (multiple atmospheric rivers in a month, loosely based on 1862)
Paleoflood research suggests much larger floods have occurred historically, possibly compounding future climate shifts.

<table>
<thead>
<tr>
<th>Water year</th>
<th>Annual peak streamflow (ft³/s)</th>
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<tbody>
<tr>
<td>650</td>
<td>&gt;600,000</td>
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<tr>
<td>1437</td>
<td>&gt;400,000</td>
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<tr>
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<td>&gt;262,000-325,000</td>
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<td>1932</td>
<td>21,100</td>
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</tbody>
</table>

Water year 650: > 600,000 cfs  
1437: > 400,000 cfs  
1574: > 400,000 cfs  
1711: > 400,000 cfs  
1862: 262,000-325,000 cfs  
1986: 134,000 cfs (reservoir affected) 
1997: 117,000 cfs (reservoir affected)  

Natural Flow Estimates  
1986: 259,000 cfs  
1997: 298,000 cfs  

England et al., 2017, USGS Bulletin 17c
San Francisco: 10-300 cm by 2100, depending on scenario and uncertainty in response

Delta: ~0-375 cm by 2100, due to differences in vertical land motion from SF
Conclusions

• Delta is at risk from sea-level rise *and* future extreme floods
• Subsidence is compounding risk
• “Lost and forgotten” records can help us better assess trends and make better, localized projections and risk assessment